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**VOLCANO MORPHOMETRY AND VOLUME SCALING ON VENUS:** J. B. Garvin<sup>1</sup>, and R. S. Williams Jr.<sup>2</sup>; (1) NASA Goddard, Geodynamics Branch, Code 921, Greenbelt, MD 20771; (2) U. S. Geological Survey, Quisset Campus, Woods Hole, MA 02540

A broad variety of volcanic edifices have been observed on Venus, ranging in size from the limits of resolution of the Magellan SAR (i.e., hundreds of meters), to landforms over 500 km in basal diameter [1, 2]. One of the key questions pertaining to volcanism on Venus concerns the volume eruption rate or VER, which is linked to crustal productivity over time. While less than 3% of the surface area of Venus is manifested as discrete edifices larger than 50 km in diameter, a substantial component of the total crustal volume of the planet over the past 0.5 Ga is related to isolated volcanoes, which are certainly more easily studied than the relatively diffusely defined plains volcanic flow units. Thus, we have focused our efforts on constraining the volume productivity of major volcanic edifices larger than 100 km in basal diameter. Our approach takes advantage of the topographic data returned by Magellan, as well as our database of morphometric statistics for the 20 best known lava shields of Iceland, plus Mauna Loa of Hawaii [3]. As part of this investigation, we have quantified the detailed morphometry of nearly 50 intermediate to large scale edifices, with particular attention to their shape systematics. We found that a set of venusian edifices which include Maat, Sapas, Tepev, Sif, Gula, a feature at 46°S, 215°E, as well as the shield-like structure at 10°N, 275°E are broadly representative of the ~400 volcanic landforms larger than 50 km described by Head and colleagues [1, 4]. The cross-sectional shapes of these 7 representative edifices range from flattened cones (i.e., Sif) similar to classic terrestrial lava shields such as Mauna Loa and Skjaldbreidur [3], to rather dome-like structures which include Maat and Sapas. The majority of these larger volcanoes surveyed as part of our study displayed cross-sectional topographies with paraboloidal shapes, in sharp contrast with the cone-like appearance of most simple terrestrial lava shields.

In order to more fully explore the differences between large venusian edifices and volcanoes on the Earth and Mars, we developed a volume scaling algorithm which relies on conservation of volcano morphometry as basal diameter is varied; this approach suggests that virtually all of the venusian edifices that were examined are a factor of 5 to 15 less productive in terms of integrated edifice volume than well-constrained terrestrial structures such as Mauna Loa or Skjaldbreidur. Only Arsia Mons on Mars displays a pattern similar to venusian volcanoes such as Maat Mons. As a final demonstration of the fundamental differences between larger volcanoes on Venus and terrestrial shields, we have employed surface cylindrical harmonic series expansions to the Magellan topographic data for over a dozen features, in comparison with cylindrical harmonic models of two classic terrestrial lava shields, Skjaldbreidur (Iceland) and Mauna Loa (Hawaii). Results of this analysis convincingly demonstrate that only Sif Mons comes close to approximating the topology of canonical basaltic shields as found on Earth. Thus, our ongoing survey of the morphometric characteristics of large-scale volcanoes on Venus suggests that the vast majority of these features should not be classified as "terrestrial shield volcanoes", in spite of their shield-like SAR backscatter patterns [1-5].

On Earth, composite basaltic shield volcanoes such as Mauna Loa display integrated edifice volumes of approximately  $10,000 \text{ km}^3$  (at a characteristic length scale of ~100 km). If a Mauna Loa style volcano were to be "scaled" to permit comparison with its 200 to 500 km diameter venusian counterparts, then a total volume of nearly 10 million  $\text{km}^3$  would result if simple proportional growth in the absence of extensive erosion were in effect. We have developed an algorithm to facilitate both proportional and non-proportional shape and volume scaling of volcanoes, using as input an average volcano topographic cross-section or complete digital elevation model. When monogenetic lava shield volcanoes such as are found in Iceland (i.e., Sandfellshaed and Lambahraun) are scaled to venusian diameters, the resulting total edifice volumes fall in the range of 1-5 million  $\text{km}^3$  (at Maat Mons length scales). Maat Mons itself displays a total edifice volume, as measured from Magellan GxDR topography, of  $360,000 \text{ km}^3$  (with an error of +/- 10%). The proportional volume scaling parameter, here defined as the constant  $k$  in a power law growth function of the form:  $V = k D^3$ , where  $V$  is volume and  $D$  is basal diameter, ranges from 0.0005 to 0.0025 for most venusian volcanoes larger than 50 km, while typical Earth shields display  $k$  values in the 0.0105 to 0.0120 range.

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In contrast, the largest of the Tharsis edifices on Mars, Olympus Mons, has a  $k$ -value near to 0.0090, within 10% of those values derived for terrestrial shields.

Using these scaling laws, and the population of major volcanoes on Venus as described by Head and colleagues [1, 3], the order of magnitude cumulative volume of crustal volcanic materials on Venus contributed by discrete volcanoes is  $\sim 13$  million  $\text{km}^3$ . This represents a global layer thickness equivalent of 28-30 m over the past 0.5 Ga for Venus, which is probably on the order of 30 to 50 times less than the crustal production from flood "basaltic" eruptions. The several hundred larger-scale edifices on Venus, however, provide a useful perspective on the styles and rates of volcanism on the planet. For example, if Maat-style composite volcanoes represent one end-member eruption pattern for Venus, and if such edifices are the venusian equivalent of terrestrial basaltic shield volcanoes, then they would only require 0.13 to 1.3 Ma to construct, ignoring erosion. Even at the low average volume eruption rates typical of terrestrial shield-building eruptions (i.e.,  $10\text{-}100 \text{ m}^3/\text{s}$ ), the largest edifices on Venus would only require 1-10 Ma for complete construction. Thus, it is impossible that the population of larger volcanoes catalogued on Venus by Head, Crumpler and others [4] is the manifestation of only the last 10 Ma of localized volcanic activity on Venus. If the 20 to 30 lava shields that formed within the  $103,000 \text{ km}^2$  area of Iceland over the past 15,000 years is only 10% of the total volume of extruded volcanic materials over the same time interval [6], then the total volume of those flood basalt eruptions on Venus that occurred simultaneously with the construction of the observed population of larger volcanoes could have exceeded 130 million  $\text{km}^3$ , for a global layer thickness equivalent of almost 300 m (in only 10 Ma). Given the abundant evidence for extensive plains volcanic deposits on Venus, it is plausible that the crustal productivity over the past 100 Ma is enough to have overplated much of the rolling plains to a depth of several kilometers. This scenario, of course, assumes the dominance of basaltic volcanism on Venus, notwithstanding the lack of morphometric evidence for large-scale terrestrial-style basaltic shields on the planet, with the possible exception of Sif-like landforms. Perhaps relatively low volume eruption rate basaltic eruptions are commonplace and essentially continuous in any time interval on Venus, and there are other unique factors which explain the dissimilarity of major venusian edifices with respect to typical Earth shields [4, 5].

The normalized (to edifice basal diameter  $D$ ) volume productivity trend for 21 venusian volcanoes can be compared against that derived for the record of post-glacial lava shield volcanoes in Iceland; for Venus  $V \sim D^{2.7}$ , while for Earth  $V \sim D^{2.9}$ . It is clear that only the largest of the Venus edifices (such as Maat and Tepev) come close to following the terrestrial shield trend, suggesting that most of the intermediate to large volcanic features on Venus are not constructed by means of sustained effusive activity, but instead involve sporadic high effusion rate episodes, perhaps including limited pyroclastic activity. Much of the anomalously high eruption rate activity that may be required to form large-scale edifices on Venus must occur in a localized summit region, in order to explain the shape trend (domical) displayed for most venusian volcanoes larger than 50 km in diameter. The significance of these observations with respect to the geologic history of volcanism on Venus is that the pattern is distinctively Earth-like; that is, the larger and greatest relief volcanic structures are perhaps geologically anomalous with respect to "average" eruption style plains volcanism, and may require pyroclastic activity. In addition, there is a reasonable possibility that the several hundred larger-scale edifices identified on Venus [4] are extremely recent features, and that these landforms are a window on the geologically most accessible record of volcanism. *{We gratefully acknowledge the support of the VDAP program, under RTOP 889-62-10-41; special thanks to Steve Baloga at PG&G}.*

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